THE UNIVERSITY OF MICHIGAN

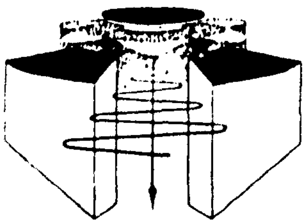
RESEARCH AND DEVELOPMENT ON HIGH-POWER CRESTATRONS FOR THE 100-300 MC FREQUENCY RANGE

QUARTERLY PROGRESS REPORT NO. 11

Period Covering January 1, 1963 to April 1, 1963

ELECTRON PHYSICS LABORATORY

Department of Electrical Engineering



By: G. T. Konrad

Approved by: J. E. Rowe

April, 1963

CONTRACT WITH:

NAVY DEPARTMENT BUREAU OF SHIPS, ELECTRONICS DIVISION,
CONTRACT NO. NObsr-81403, INDEX NO. SF-0100201.

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THE UNIVERSITY OF MICHIGAN
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J. E. Rowe, Director
Electron Physics Laboratory

Project 03783

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ABSTRACT

In the electrostatic focusing system employing the $P_\mu = 4.46$ hollow-beam gun it is shown that a substantial portion of the observed beam interception is due to secondary electrons. One method of reducing this effect is shown. Scaling the $P_\mu = 4.46$ gun to a value of 20 is described.

Two 100-watt Crestatrons have been tested at reduced power due to a poor r-f match in the first tube and to high beam interception in the second tube. It is apparent from the data, however, that most of the design objectives have already been easily met. These are a full 3 to 1 bandwidth under small-signal as well as saturation conditions, more than enough small-signal gain and quite encouraging values of conversion efficiency.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PERSONNEL

Scientific and Engineering Personnel		Time Worked in Man Months*
J. Rowe	Professor of Electrical Engineering	.11
C. Dolph	Professor of Mathematics	.05
C. Yeh	Associate Professor of Electrical Engineering	.15
R. Lomax	Visiting Assistant Professor of Electrical Engineering	.28
A. Singh	Research Engineer	.23
J. Boers	Associate Research Engineers	.23
G. Konrad		.65
J. Kurtz		.13
W. Rensel	Assistant Research Engineer	.27
A. Collins	Research Assistants	.13
J. Loh		.39
C. Rhee		.86
Service Personnel		6.21

* Time Worked is based on 172 hours per month.

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1. Introduction (G. T. Konrad)

Contract NObsr-81403 comprises a research and development program on high-power 100-300 mc Crestatrons. The aim is to construct compact 100-watt Crestatrons employing permanent magnet focusing. Initially the tubes will be tested in a solenoid until they meet electrical specifications. Ultimately the permanent magnet focused tubes employing a depressed potential collector will be ruggedized so as to meet environmental specifications. This work is being conducted by the Bendix Research Laboratories on a subcontract from The University of Michigan.

Theoretical as well as experimental studies on high-perveance hollow-beam electron guns, in addition to electrostatic focusing systems initiated some time ago on this program, are being continued by The University of Michigan. The ultimate goal of these studies is to demonstrate the feasibility of using electrostatically focused, high-power, hollow electron beams in microwave devices.

2. Hollow-Beam Gun Work (G. T. Konrad)

During the past quarter the $P_{\mu} = 4.46$ gun was again operated in the beam analyzer in conjunction with the focusing tester. As was mentioned in the last quarterly report there has been evidence of quite large secondary electron emission in the focusing tester. The secondary electrons are believed to be generated when the beam grazes the focusing disks as it passes through the electrostatic focusing region. In order to overcome some of these difficulties a carbon coating was applied to the focusing disks and a decrease in the current intercepted by some of these disks was indeed observed. It is believed that the poor transmission through the focusing region is largely due to secondary electrons, as has been mentioned in previous progress reports. The experimental results for similar conditions of beam voltage and current are shown in Fig. 2.1. The curve labeled "No Coating" was obtained in previous tests. It is evident that a marked improvement in beam transmission was obtained when the secondary emission was reduced. The abscissa of Fig. 2.1 is a measure of the focusing potential, because V_+ is the high focusing voltage, V_- is the low focusing voltage and V_o is the average beam voltage.

The $P_\mu = 4.46$ gun has been scaled up in perveance to a value of $P_\mu = 20$. The design in the electrolytic tank has been completed. At the present time the gun geometry is being programmed for the digital computer, where space-charge effects can be taken into account. The trajectories to be obtained from this program will be similar to those shown in previous progress reports for the $P_\mu = 4.46$ gun.

3. Work Conducted at the Bendix Research Laboratories*

3.1 General Description of the Metal-Ceramic 100-Watt VHF Crestatrons.

Two tubes were tested during this report interval. The first tube was basically of metal-ceramic construction except that some glass-to-metal components were utilized to expedite assembly and testing. Thus the input and output r-f vacuum feedthroughs and the stem header contained glass-to-metal seals. The kovar in these parts caused distortion

* This material was submitted by Dr. J. G. Meeker of the Bendix Research Laboratories.

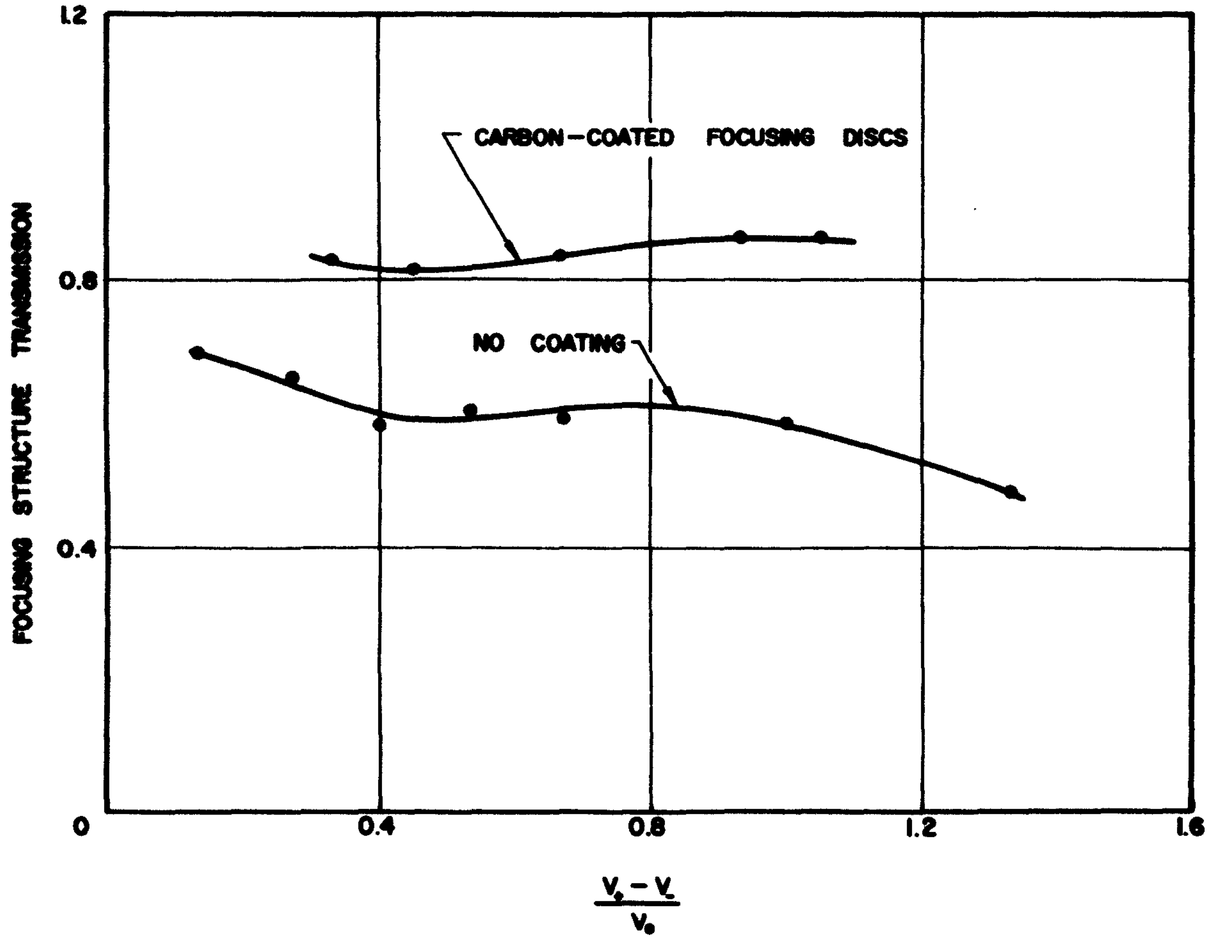

FIG. 2.1 COMPARISON OF BEAM TRANSMISSION FOR CARBON-COATED AND UNCOATED FOCUSING DISKS AS A FUNCTION OF THE FOCUSING POTENTIAL.

in the magnetic focusing field with attendant high helix current interception. The second tube, an all metal-ceramic model, incorporated a helix of somewhat coarser pitch in order to raise the operating voltage to the design value. Important tube parameters are listed in Fig. 3.1.

The helix in each tube was mounted on three precision-ground ceramic rods which located it concentrically within a stainless steel envelope of a diameter 1.5 times that of the helix mean diameter. Matching sections on both ends of both tubes were identical in basic design, but attention was given to testing and adjusting each match during assembly.

The matches are based on the principle of directly connecting the coaxial lines to the helix at a point where the helix is spaced close to the shell and represents a line above ground plane with a 50-ohm impedance. The ground plane is then gradually tapered away from the helix until it blends into the envelope at the mid-section of the tube; thus the impedance varies from 50 ohms at the connectors up to its normal shielded helix value. Because the first few turns on each end of the helix are very close to the tapered matching shields, mica spacers are inserted there to provide d-c isolation.

3.2 Tube No. 1. This tube had a helix of 11.5 TPI. To expedite assembly it also incorporated glass-to-kovar r-f vacuum seals and a kovar-to-glass stem header as previously noted. The kovar parts contributed to an eventual limiting of the beam current since they distorted the magnetic focusing field, thereby causing excessive helix current interception. For this reason, the data discussed below was taken at approximately 105 ma collector current instead of the design value of 450 ma.

	PHYSICAL								ELECTRICAL							SPECIAL NOTES
	Overall Length (in.)	Helix Length (in.)	Helix Mean Dia. (in.)	Helix TPI	Helix Wire Size	Type RF Connectors	Matching Sections Type	Matching Sections Length Each End	Gun Type	Beam Dia. (Inches) Inner	Beam Dia. (Inches) Outer	Rated Collector Current	Rated Voltage	Operating Conditions for Reported Data Collector Current	Operating Conditions for Reported Data Collector Voltage	
Tube No. 1 (Bendix RLD NO. TWT-143-A-1)	16	9.6	0.756	11.5	0.030	Coax Direct Pin Conn.	Tapered Outer Shield	4"	Hollow Beam	0.478	0.590	452 (ma)	870 volts	105 (ma)	680 volts	Glass-to-kovar r-f feedthroughs and stem header
Tube No. 2 (Bendix RLD NO. TWT-143-A-3)	16	9.6	0.756	10.0	0.030	Coax Direct Pin Conn.	Tapered Outer Shield	4"	Hollow Beam	0 478	0.590	452 (ma)	870 volts	143 (ma)	700 volts	This tube developed an open inner anode and arc breakdown

FIG. 3.1 LIST OF PARAMETERS FOR THE TWO TUBES TESTED.

The r-f matching is shown in Fig. 3.2 where the percent reflected voltage is plotted versus frequency for the following three cases: the input with output isolated, the output with input isolated, and the input with output not isolated but terminated in a 50-ohm load.

It is evident that individual matches of less than 2 to 1 VSWR were achieved across the band from 100 to 300 mc. With a 2 to 1 VSWR on each end, oscillations due to these mismatches can be expected if the tube were to develop 19 db of gain. With a less than perfectly matched load, oscillations could be expected with even less gain--and did, in fact, occur whenever the gain approached 18 or 19 db during the tests.

A concise picture of the operation of the tube can be gained from the basic output-versus-input plot of Fig. 3.3. Several pieces of information can be ascertained, some of which become more apparent in other graphs such as Fig. 3.4. The most important properties of the Crestatron are the small-signal gain, saturation gain, power output and efficiency at saturation, as well as the bandwidth capability.

Recalling that the data was obtained while operating at less than one-fourth rated current, it can be seen that the performance is generally good. The bandwidth properties are quite encouraging, the 3 to 1 design objective being obtained at both small- and large-signal operation. Furthermore, the beam efficiencies obtained at saturation are approaching 20 percent without the benefit of a depressed-potential collector. (The efficiencies spoken of here, it should be noted, are not the net conversion efficiencies but include the contribution of feedthrough from input to output, which becomes a greater percentage of the output power as the tube is driven beyond saturation. In a low-gain, low-loss power tube of the Crestatron type this feedthrough power is available at the output

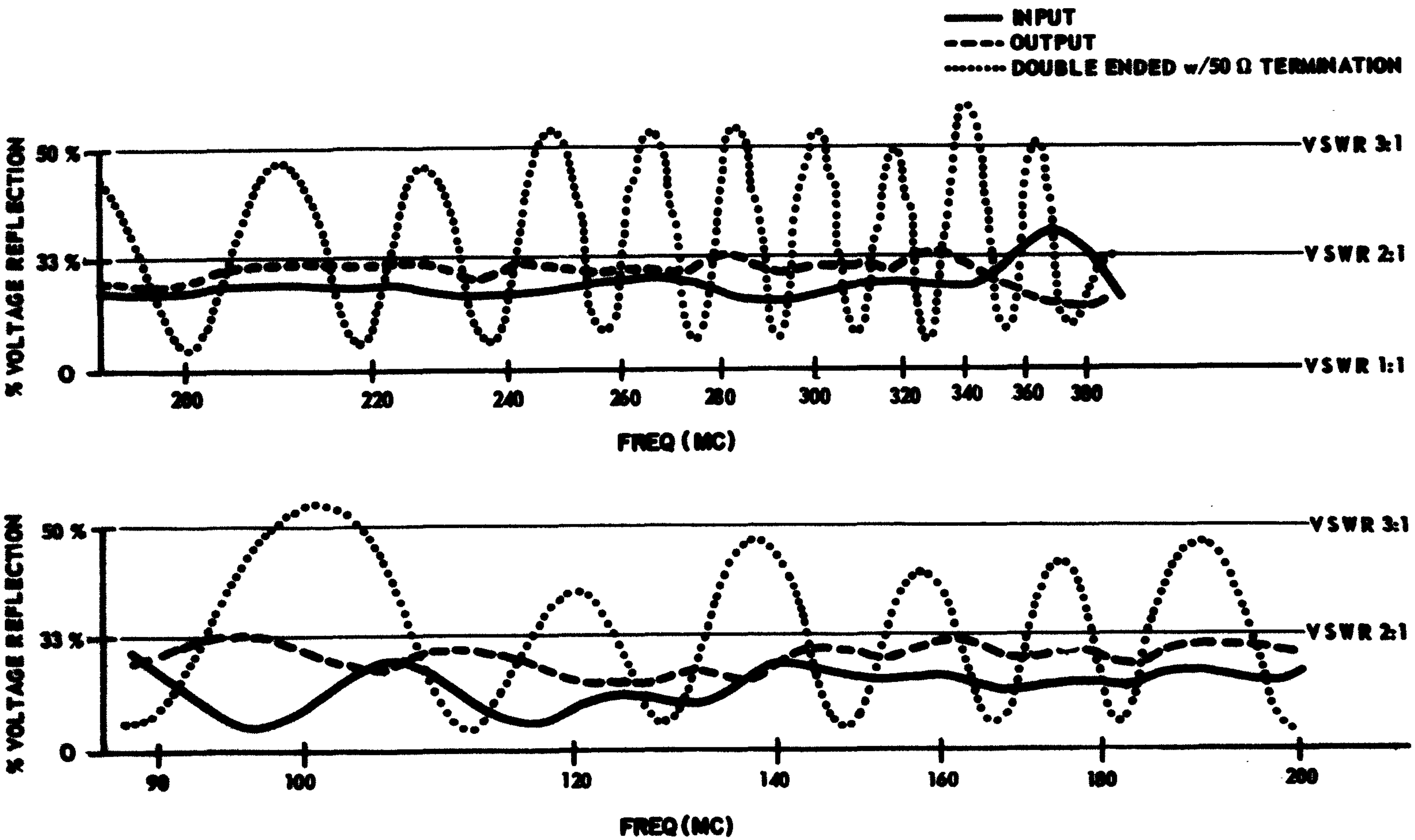

FIG. 3.2 REFLECTION COEFFICIENT VS. FREQUENCY FOR TUBE NO. 1.

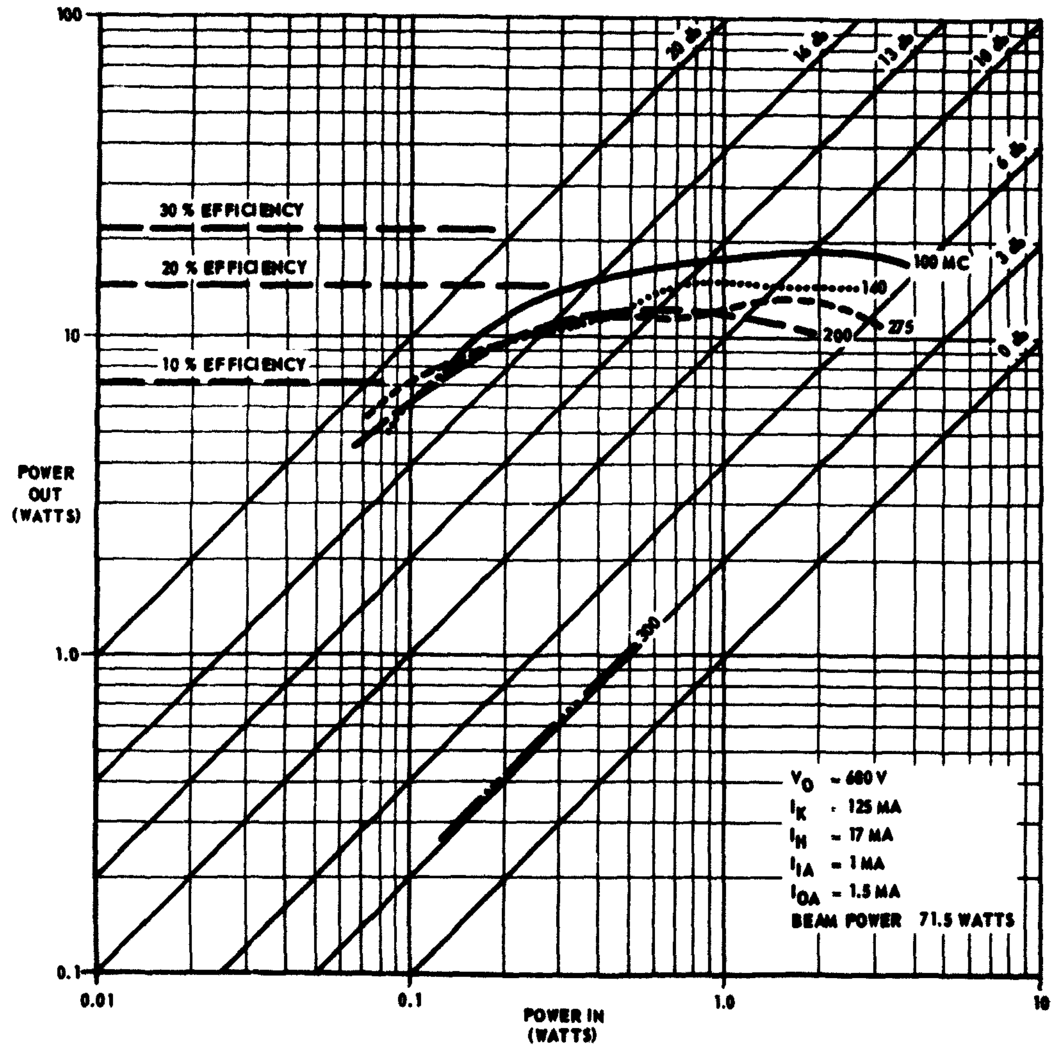

FIG. 3.3 SATURATION CHARACTERISTICS OF TUBE NO. 1.

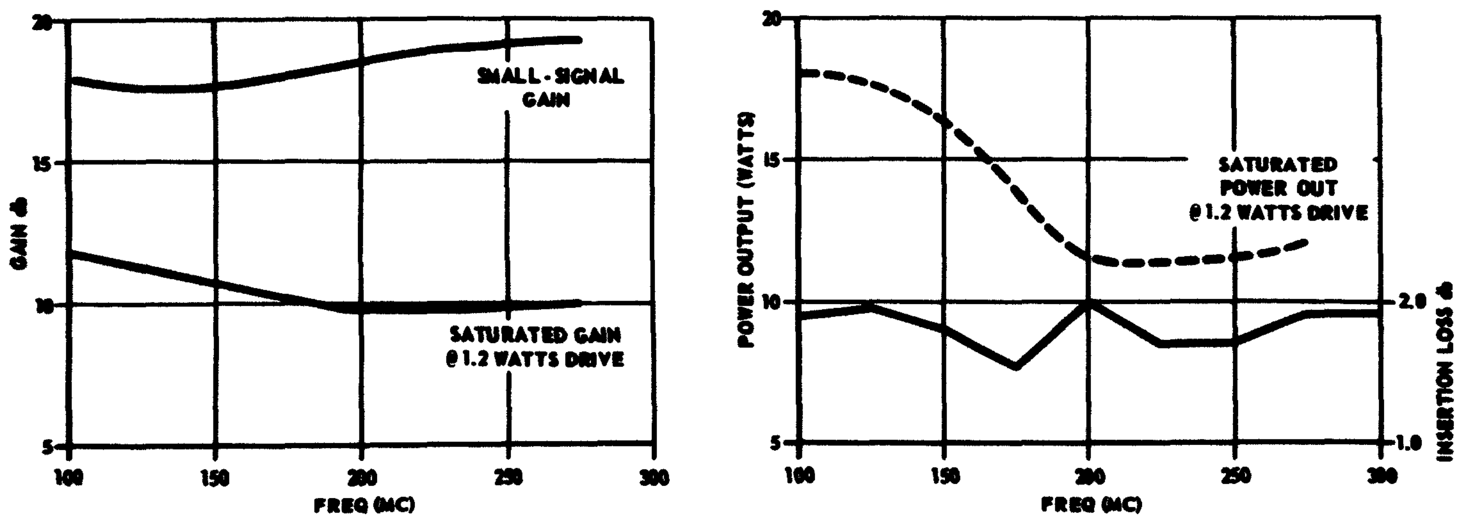

FIG. 3.4 GAIN, OUTPUT POWER AND INSERTION LOSS FOR TUBE NO. 1.

terminal and should rightfully be included in the apparent efficiency.) With regard to gain, the design goal of greater than 10 db saturation is already exceeded at even the low current, and the accompanying small-signal gain is likewise larger than necessary. This suggests that future tubes must be shortened somewhat, but also that they will easily meet the design gain objectives.

The operating voltage was a little lower than expected due, apparently, to larger loading than theoretically predicted. A modification to a coarser pitch helix was introduced into the second tube to raise the operating voltage and thereby put more power into the beam at a given current.

Finally, it should be noted that the tube stability was marginal because of the high gain (approximately 19 db) without an internal attenuator. This factor and the high interception current prevented operation of this tube at more than one-fourth rated current.

3.3 Tube No. 2. The second tube, shown in Fig. 3.5, was all metal-ceramic in construction. In addition, it was modified on the basis of information obtained from Tube No. 1. Thus, the helix TPI was changed from 11.5 to 10.0. This served a two-fold purpose: it would reduce the electrical length and hence the gain, and raise the operating voltage to near the design value of 870 volts.

After processing, when the tube was turned on, an open circuit developed in the lead to the inner anode. This severely inhibited the performance since the beam current was limited to about 140 ma, and a strong divergent lens resulted which tended to conically expand the beam. This defect was compensated in part by applying a negative voltage to the outer focusing electrode (adjacent to the cathode) and data was

FIG. 3.5 TUBE NO. 2 (BENDIX RDL TWT-143-A-3).

obtained, though at low beam current. Nevertheless, the data proved to be encouraging.

The match data is presented in Fig. 3.6 which shows the percent voltage reflection versus frequency on an expanded scale. A considerable effort was expended in adjusting each pin match to obtain as low a VSWR as possible. As a result, both matches have been held below a VSWR of 1.5 to 1 over the entire band from about 90 to 350 mc. With a perfectly matched load, such matches should allow gains of nearly 27 db before oscillation. In fact this tube did prove to be considerably more stable than the first tube. Thus, results indicate that oscillations should not be a problem if similar care is taken in adjusting the matches in subsequent tubes.

Again performance data is best summarized by the power output-versus-power input graph of Fig. 3.7 and the supplementary curves of Fig. 3.8.

Several important points are worthy of note. Firstly, the gain of the tube is lower than that of Tube No. 1 due to the shorter electrical length achieved by reducing the TPI. Secondly, the small-signal and saturation gains are quite flat, the former being within 3 db across the band while the saturation gain is within 1.5 db. Thirdly, the power output level is approximately 20 watts and the collector current is approximately one third the rated value. Anticipating an increase in efficiency as the gain parameter, C, goes up to its design value at rated current, one can reasonably expect to attain 100 watts of output power. Most important, however, was the increased stability of this tube compared to the first one due to shorter electrical length and better matches.

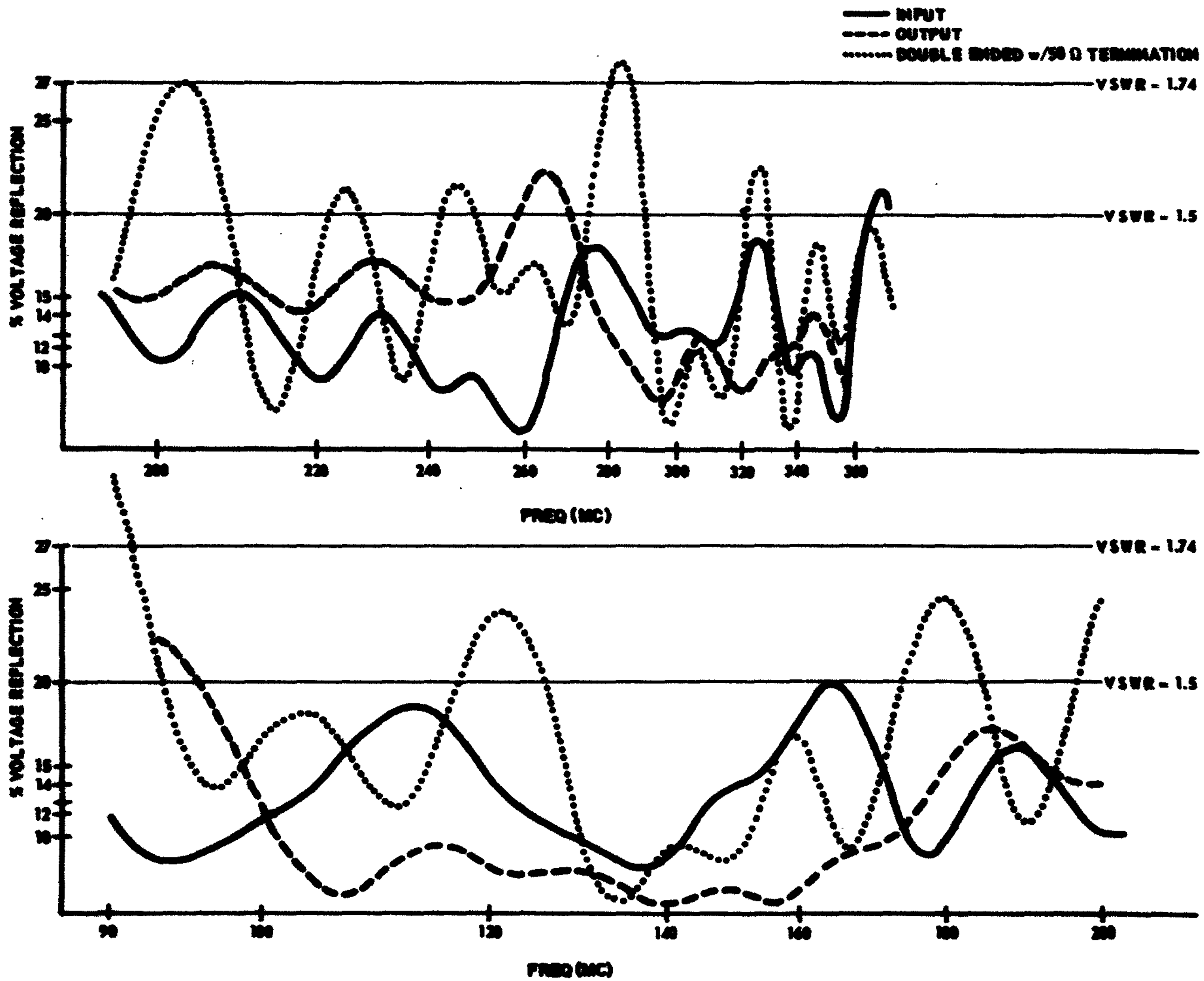

FIG. 3.6 REFLECTION COEFFICIENT VS. FREQUENCY FOR TUBE NO. 2.

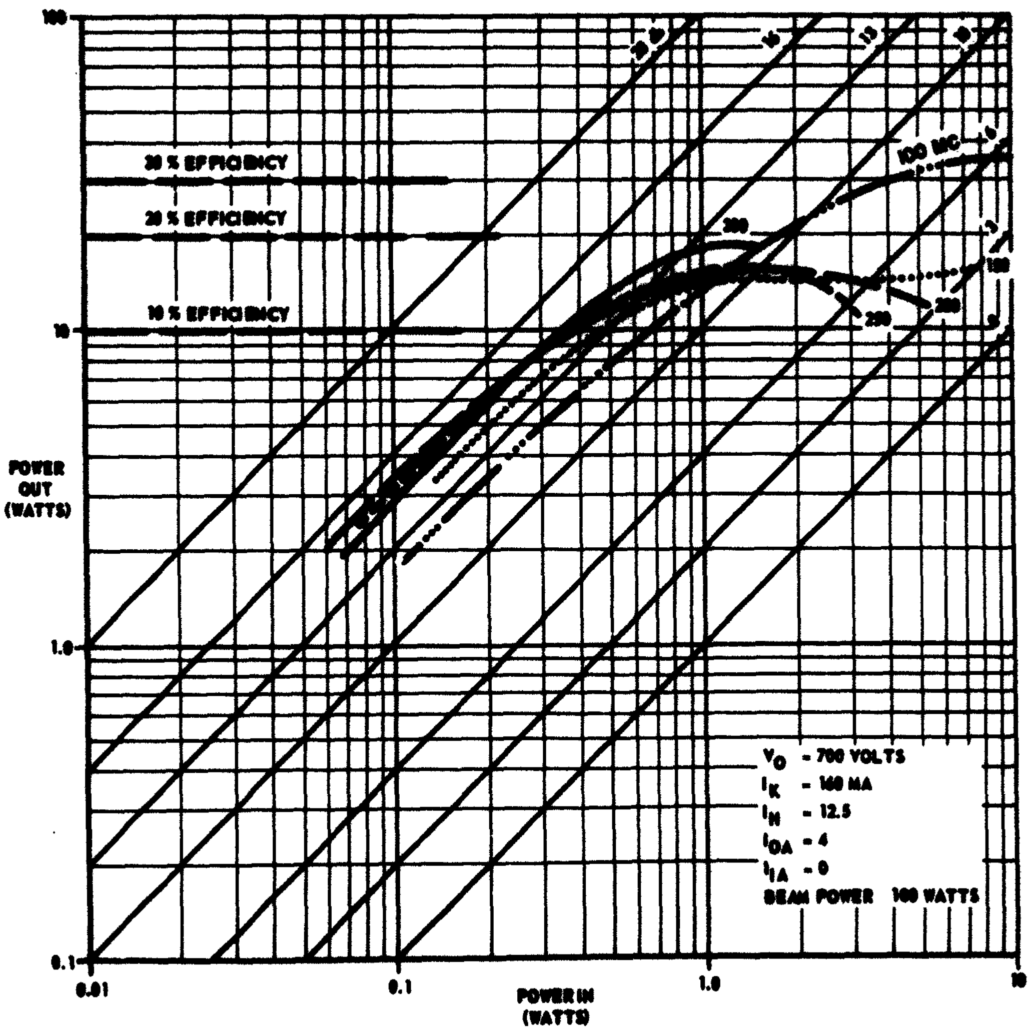

FIG. 3.7 SATURATION CHARACTERISTICS OF TUBE NO. 2.

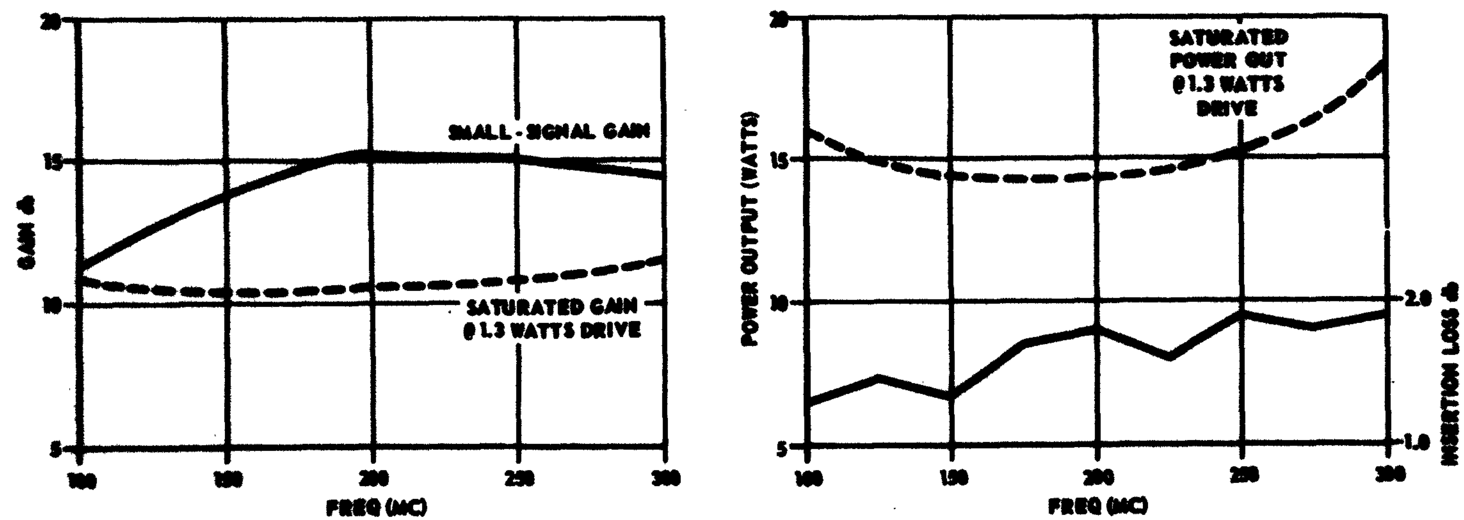

FIG. 3.8 GAIN, OUTPUT POWER AND INSERTION LOSS VS. FREQUENCY FOR TUBE NO. 2.

3.4 Discussion and Conclusions Based Upon the Experimental Data. The results from the two experimental tubes seem to bear out predicted design performance reasonably well.

The indicated bandwidth is a full 3 to 1 with small-signal gain centered at mid-band.

Saturation bandwidth, especially in the second tube, was extremely flat, and the power level at saturation, although low due to reduced beam power, gives indication of approaching the design value of 100 watts.

The gains have run consistently on the high side even in the second tube in which the helix pitch was increased to shorten the electrical length and increase the operating voltage. Thus, the helix length can be reduced below the present 9.6 inches and still meet design objectives for gain. The gain reduction would, in turn, further tend to prevent instability due to load mismatches.

Matching is the most important aspect affecting stability. These tubes have shown that pin matches can be excellently matched over a 3 to 1 band at these frequencies.

The mechanical design has proven to be sound, although some minor modifications are required. Assembly procedures and metal-ceramic seals for particular subassemblies have been major problems in the assembly of the tubes, but these have now been successfully solved. Forthcoming tubes will employ Monel and copper rather than stainless steel parts wherever possible.

3.5 Coupled-Helix Coupler Study. Although the direct pin matches from coaxial to helical lines have proven to be satisfactory broadband, low insertion-loss couplers, it also seemed desirable to investigate coupled-helix matching sections to determine their possible use over this same frequency band. Therefore, a parallel study was instituted during this quarter, and completed with satisfactory results.

Several coupled-helix designs were tested. The variables were the ratio of diameters of the coupling helix and the tube helix, and the TPI of the coupling helix. A high alumina spacer between the helices will permit the design to be used in a metal-ceramic tube.

The final and most successful coupler uses a coupling helix with a diameter 1.5 times that of the tube helix. A cross section of this coupler is shown in Fig. 3.9. An empirically-designed shield and a 50-ohm internal load in the reverse direction (in the vicinity of point X) are necessary to satisfactorily achieve a match. Under these conditions, the VSWR across the band is less than 2 to 1 as shown in Fig. 3.10.

4. Summary and Future Work (G. T. Konrad)

The work on the $P_{\mu} = 4.46$ gun has been completed. The performance of the gun is quite satisfactory so that it appears worthwhile to incorporate it into the electrostatically focused 100-watt tube. This will be done in the near future. The $P_{\mu} = 4.46$ gun is being scaled to $P_{\mu} = 20$. Most of the modified components have been manufactured. Construction and testing of the gun await the outcome of the digital computer solutions.

Two 100-watt Crestatrons have been operated at reduced power. The results indicate that the electrical specifications should be readily achievable when future tubes will be operated at rated beam power. Based on present experimental results, and in line with program objectives, future work will be directed along the following lines.

The next tube constructed will be physically shorter, because the tubes in the past had too large a gain. This modified tube is now in the final stages of assembly. In subsequent tubes it is planned to incorporate

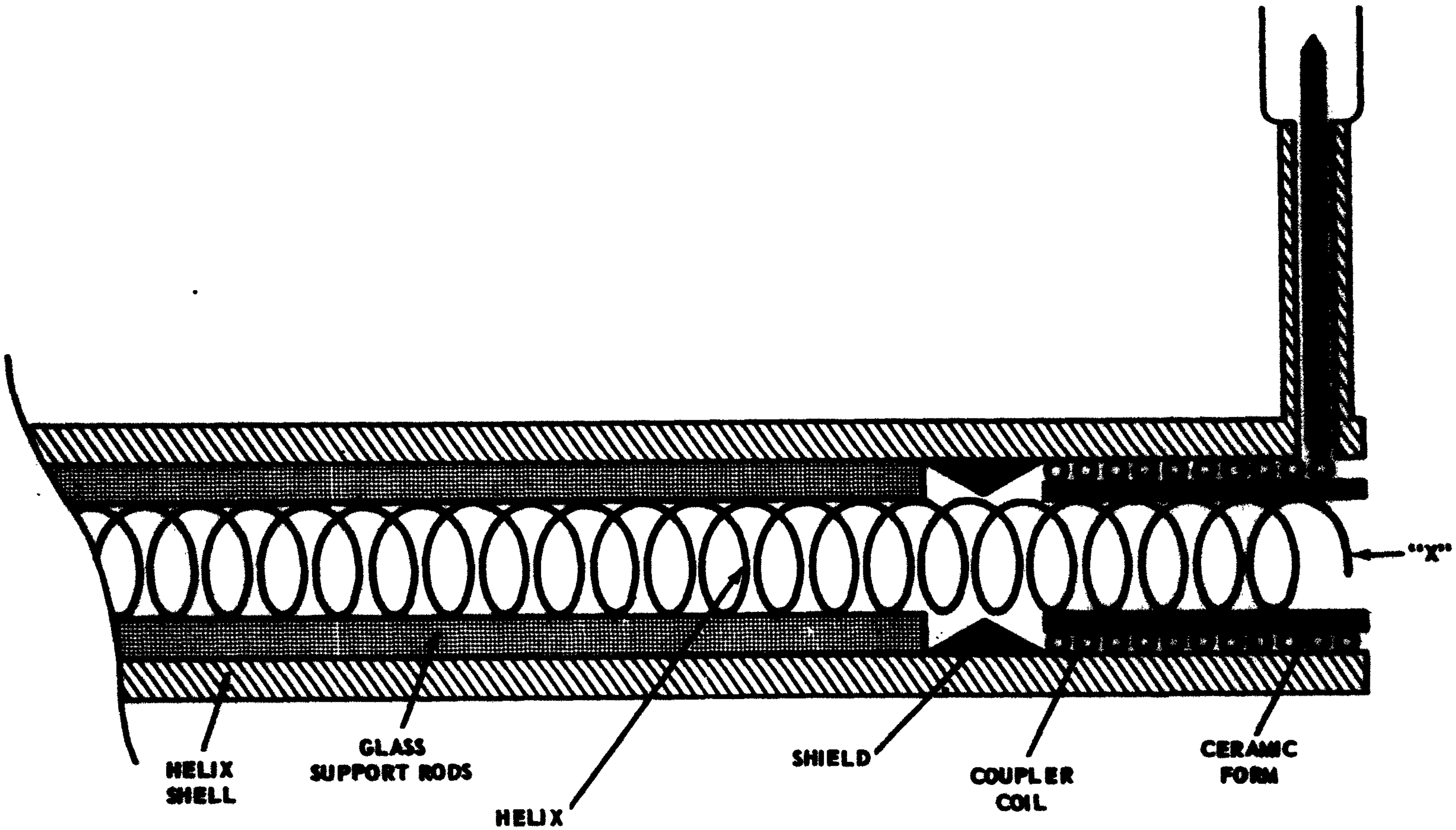

FIG. 3.9 CROSS-SECTION OF COUPLED-HELIX COUPLER.

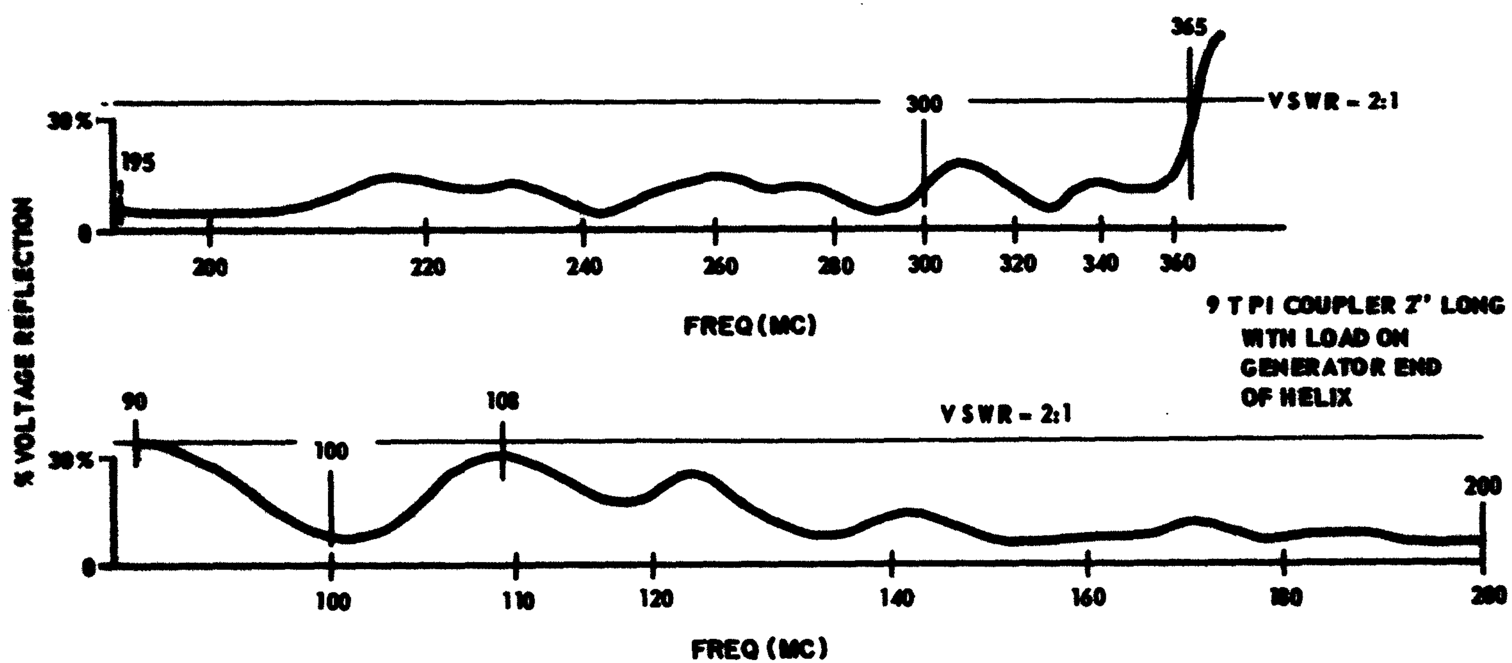

FIG. 3.10 REFLECTION COEFFICIENT VS. FREQUENCY FOR THE COUPLED-HELIX COUPLER.

depressed potential collectors. Nearly a 40 percent improvement in over-all efficiency is anticipated. Another method of efficiency improvement will be investigated, namely variable-pitch helices. It is planned to conduct cold tests on such helices in the near future. Past experience has shown that coupled with an improvement in conversion efficiency an increased stability is common for tubes using variable pitch slow-wave circuits. As soon as full power data has been obtained for the solenoid focused tubes it is planned to introduce permanent magnet focusing.

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